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IS POPULATION GROWTH REALLY BAD FOR LDC'S IN THE LONG RUN? A RICHER SIMULATION MODEL

Julian L. Simon

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A RICHER SIMULATION MODEL*

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INTRODUCTION

There is a fundamental contradiction in economic knowledge concerning the effect of population growth in less-developed countries (LDC's hereafter). On the one hand, the main theoretical elements suggest that more population retards the growth of output per worker.** The overwhelmingly important element in the theory is Malthusian diminishing returns to labor as the stock of capital (including land) does not increase in the same proportion as does labor. Another important theoretical element is the dependency effect, which suggests that saving is more difficult for households when there are more children, and that higher fertility causes social investment funds to be diverted away from industrial production. Combined together in simulation models (e.g., Coale and Hoover, 1958; Enke et al, 1971), these elements suggest that relatively high fertility and positive population growth have a negative effect upon output per

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* I am very grateful to Stanley Engerman, Allen Kelley, Ronald Lee, and Nathaniel Leff for unusually thoughtful and valuable suggestions at an early stage of this work. I also appreciate comments from Folke Dovring, Larry Neal, Robert Solow and Etienne vandeWalle. And the opportunity to present this paper and receive criticism at an Asia Society SEADAG Conference was of great value. I will long be thankful to Robbie Cohen for her extraordinary help in programming and executing the computer model. Dan Weidenfeld and Carlos Puig made valuable programming contributions at a crucial point. And it's about time I acknowledged Olga Nelson's wise and skilful typing.

** Output per worker or output per worker hour, and not income per person or income per consumer equivalent, is the appropriate measure of the productive power of an economy. And productive power rather than the quantity of consumption would seem to be the underlying concept in economic development. Hence output per worker (Y/L) is the measure of performance used throughout this paper.

worker (and an even more negative effect upon income per consumer equivalent, because the proportion of consumer equivalents to workers is higher when fertility is higher).

But the empirical data do not support this a priori reasoning. First, there is the historical fact that population grew at an unprecedented rate during the period of Europe's development from 1650-1750 onwards. And economic historians (e.g., Mathias, 1969; Deane and Cole, 1964; Eversley, 1965, 1967) have concluded that slower demographic growth would have hampered England's economic development. And there is no significant correlation in the historical series of population growth and economic growth over the past century or half century in those countries now regarded as developed. Second, the cross-sectional evidence from among the presently-developing countries on the overall relationship between contemporary population growth and economic growth certainly does not reveal a consistent pattern. Easterlin, Kuznets, Conlisk and Huddle, and Thirlwall all arrayed LDC countries by their recent population growth rates and their economic growth rates, to examine for a relationship between the two: (a) Easterlin's assessment of his data is that "It is clear from the table that there is little evidence of any significant association, positive or negative, between the income and population growth rates." (1967) (b) Kuznets (1967) compiled data on 21 countries in Asia and Africa, and 19 countries in Latin America. In the separate samples, and in the 40 countries together, there is not a significant negative correlation between population growth and growth of per capita product; the coefficients are actually positive though very weak. (c) Conlisk and Huddle (1969) regressed the output growth rate on the

savings rate and the rate of population growth, over roughly 1950-1963 across the 25 LDC's that receive AID. The coefficient of population growth was .692 (t=3), suggesting that an increment of population has, ceteris paribus, a positive effect on growth. (d) Thirlwall (1971) regressed the percent change in output on the percent change in population over 1950-1966 in 32 countries, and obtained a coefficient just below unity, .907. (e) Chesnais and Sauvy (1973) analyzed the relationship between demographic and economic growth in the 1960's for various samples of up to 76 LDC's. and found non-significant correlations (mostly slightly positive). They also re-analyzed Stockwell's (1972) finding of a negative relationship and found it to be statistically unfounded. These overlapping empirical studies certainly do not show that fast population growth in LDC's increases per capita income. But they certainly do imply that one should not confidently assert that population growth decreases per capita economic growth in less-developed countries.

Habakkuk points out, however, that: "There is no lack of possible mechanisms by which an increase in population could in principle have...favorable repercussions on income." (1963, p. 614). And recent research has shown that some of the possible mechanisms actually do operate (e.g., Boserup, 1965; Mendels, 1970; deVries, 1969; Chenery, 1960).

Contradiction cries out for reconciliation. But there are no economic ideas that are serious candidates to effect such a reconciliation. Economies of scale may work to mitigate the effects of population growth, but no one except Clark (1967) believes that they are enough to nearly offset even the capital-dilution effect. Kuznets (1965) suggests that institutions are the key, and that demography by itself is not a major factor in development, but in my judgment this difficult-to-work-with conclusion should not be accepted until economic explanations have been exhausted.

When the theory and the data do not jibe, either (or both) may need re-examination. This paper re-examines the theory. A model is constructed

that includes the elements of the standard models, but that also embodies other elements discussed in the qualitative literature as being important: demand effects upon investment (emphasized by the historians of England), the work-leisure choice (Tussing, in Kelley et al, 1971, writing on Japan), variations in work activity as a function of differences in needs and standard of living (Myrdal, 1968, Chapter 22), and economies of scale (Chenery, 1960). The model also embodies elements recognized elsewhere in the development literature as important: intersectoral shifts in labor (Lewis, 1955), depreciation (Enke, 1963), and land building (Slicher van Bath, 1963). The model solves by utility maximization - finding the highest current leisure-output indifference curve that touches the current production function. The allocation of labor to the agricultural and industrial sectors, and the outputs of the two sectors, are found as a function of observed elasticities of demand and allocations of output at different income levels in LDC's.

Using a variety of parameters, the simulation indicates that positive population growth produces considerably better economic performance in the long run (120 to 180 years) than does a stationary population, though in the short run (60 years), the stationary population has very slightly better performance. A declining population does very badly in the long run. And in the experiments with the "best" estimates of the parameters for a representative Asian LDC (the "base run") moderate population growth doubling over 50 years) has better long-run performance than either fast population growth (doubling over 35 years) or slow population growth (doubling over about 200 years). Experiments with one variable at a time reveal that the difference between these results and previous theoretical studies

is produced by the combination of the novel elements - the leisure-output work decision, economies of scale, the accelerator investment function, and depreciation; no one factor is predominant. Perhaps the most important result is that within the range of positive population growth, different parameters lead to different rates of population growth as "optimum." This means that no simple qualitative theory of population growth can be very helpful.

THE MODEL

This description of the model skims quickly over the aspects that are commonly found in such models, and dwells on the novel aspects. Additional reasoning behind the specification, and data underlying the parameters, is forthcoming in a longer work, parts of which are now available upon request. The variables and equations are listed in the appendix. Also given there is a schematic of the model (Figure 3).

Output (Q_F) in the agricultural sector (denoted by F for "farm"), is made a Cobb-Douglas function of land plus other physical capital together (K_F), labor in man-hours (M_F), social capital (J), and the level of agricultural productive efficiency at that point in history (A_F):

$$Q_{F,t} = A_{F,t} K^{\alpha}_{F,t} M^{\beta}_{F,t} J_t. \qquad (1)$$

The exponents of α and β in the base run are .5 and .5; the conclusions are not different with other exponents, however.

Social overhead capital, which is treated together with economies of scale, is made a function of total labor force (L_t):

$$\frac{J_{t+1} - J_t}{J_t} = a_{112} \left(\frac{L_t - L_{t-1}}{L_{t-1}}\right). \qquad (2)$$

The parameter a_{112} is .20 in the base run (Chenery, 1960).

Runs are also made with elasticities of .40 and of 0 to see the importance of the scale parameter.

Agricultural investment* is made a function of the "gap" between the aspired-to amount of farm capital and the actual amount of farm capital:

$$\frac{K_{F,t+1} - K_{F,t}}{K_{F,t}} = a_{1140}\,GAP_t - a_{1141}. \qquad (3)$$

The aspired-to level of farm capital is made a multiplicand of farm capital and technological efficiency, and is set at four times the output, because all over the world the value of agricultural capital is very close to four times as large as the value of a year's gross output (Buck, 1930; Clark, 1957; Gov. of India, various years):

$$GAP_t = \frac{4Q_{F,t} - A_{F,t}\,K_{F,t}}{A_{F,t}\,K_{F,t}}, \qquad (4)$$

where $A_{F,t}$ is initially set at .25 ** and $K_{F,t}$ is initially set at $4\,Q_{F,t} = 0$.

The farmer is assumed to make up some proportion of the gap in each year - 25% is the proportion in the base run. That is, the coefficient a_{1140} in equation (3) is set at .25 in the base run, and takes other values in other runs. The term a_{1141} stands for depreciation*** and is set at .005 in the base run; it is varied in other runs.

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* Agricultural investment in this context includes land clearance, local irrigation, and construction of tools. The input of such investments is mostly off-season labor by farmers.

** More specifically, $A_{F,t}$ and $K_{F,t}$ are initially set to allow for the 4/1 capital-output ratio in agriculture.

*** The response functions for investment and technology in both sectors are constrained to be non-negative. Depreciation can, however, drive net investment negative on balance and does so in some trials.

The agricultural investment function and the agricultural production function together have the unusual property that no conservation equation connects them. That is, investment and production for current consumption do not trade off within total production. This is because in peasant agriculture investment is mostly not a held-back part of total production. The labor devoted to crop production is mostly not in competition with the labor devoted to clearing new fields, irrigation works, and so on; rather, the two activities take place in different seasons.

The absence of conservation is part-and-parcel of the model not being constructed as a closed resource system equilibrated by rational economic behavior on the part of producers and wage-earners. Rather the system is an open set of equations each chosen pragmatically for its representation of a relevant aspect of a dynamic production-consumption system; the marginal products of labor and capital are therefore not kept equal in the agricultural and industrial sector. This approach is less esthetic from the standpoint of economic theory than is a neo-classical economic-development model such as that of Kelley et al. (1972). But there are two justifications for this choice. First, attempting to construct this model in neo-classical terms would run up against fundamental theoretical problems such as the valuation of land and other agricultural capital that was formed hundreds of years earlier (an income-stream approach being circular here). And a neo-classical model embodying a labor-leisure choice by workers would require breaking new ground in that direction (though see Sen, 1966; Yotopolous and Lau, 1973). Second the appropriate comparison of this model and its results is to Coale-Hoover (1958), Enke et al. (1969), and perhaps Limits to Growth. That is, the appropriate and fair comparison is to other models whose primary aim is the same as this model - to assess

the effects of different rates of population growth on the rate of economic development - rather than to models which aim to accomplish other purposes.*

The gain-in-technological-knowledge function in agriculture is made to depend only on time, as seems appropriate in most LDC agriculture. (Switches in technique of the sort Boserup, 1965, emphasizes are embodied in the production function.)

$$A_{F,t-1} = a_{115} A_{F,t} \qquad (5)$$

with a_{115} = 1.0025 in the base run, and other values in other runs.

The labor-supply function will be described later in the context of the integrated two-sector model.

Now for the industrial sector (denoted by the subscript G) ~~. The industrial~~ production function is

$$Q_{G,t} = A_{G,t} K^{\gamma}_{G,t} M^{\varepsilon}_{G,t} J_t \qquad (6)$$

Exponents are γ = .4 and ε = .6 in the base run.

Technological change in industry is a function of both time and the change in output:

$$A_{G,t+1} = A_{G,t} + a_{1170} A_{G,t} + a_{1171} \log \left(\frac{Q_{G,t} - Q_{G,t-1}}{Q_{G,t}} \right) A_{G,t} \qquad (7)$$

$$\log \frac{Q_{G,t} - Q_{G,t-1}}{Q_{G,t}} \geq 0$$

where a_{1170} is .0025 and a_{1171} is .001, respectively, in the base runs.

Industrial investment is made to depend upon the change in industrial output. It also depends upon the burden of youth dependency. And there is a deduction for depreciation:

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* It should be noted that though the neo-classical sort of "sacrifice" - the choice between investment and consumption - is not found in this model, the model does embody the choice of "sacrificing" labor for more agricultural investment and especially for more current production. This latter choice, in turn, is left out of the neo-classical models. So, on balance, this model would seem to need little apology on this score.

$$K_{G,t+1} = K_{G,t} + a_{1181} \log \left(\frac{Q_{G,t} - A_{G,t-1}}{Q_{G,t}}\right)\left(1 - a_{1182}\, YOUTH_t\right)\left(K_{G,t}\right)^{a_{1183}} K_{G,t}$$

$$\log \frac{Q_{G,t} - Q_{G,t-1}}{Q_{G,t}} \geq 0 \qquad (8)$$

where $a_{1181} = .0067$, $a_{1182} = -.50$ and $a_{1183} = .0025$, in the base run (other values in other runs). That is, the amount of investment that would otherwise take place is modified downwards by the youth dependency burden.* The depreciation parameter implying a 40-year life for equipment is almost surely too small; a 20-year life is probably closer to the truth in LDC's (Kuznets, 1966, Table 5.5), and some estimates have put depreciation much faster even than this in some places (Fei and Ranis, 1964, quoted in Kelley and Williamson, 1971).

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* More specifically, the absolute amount of youth dependency is calculated in this context in the same manner as Leff (1969), in order to make the parameter consistent with his estimate,

$$\left[\frac{\sum_{1}^{14}(MEN + WOM)}{\sum_{15}^{64}(MEN + WOM)}\right]$$

The burden for any year is computed as a difference between that year's burden and the base year's burden:

$$YOUTH_t = \frac{\left[\dfrac{\sum_{i=1}^{14}(MEN_i + WOM_i)_t}{\sum_{i=15}^{64}(MEN_i + WOM_i)_t}\right] - \left[\dfrac{\sum_{i=1}^{14}(MEN_i + WOM_i) \text{ base year}}{\sum_{i=15}^{64}(MEN_i + WOM_i) \text{ base year}}\right]}{\left[\sum_{i=1}^{14}(MEN_i + WOM_i) \text{ base year} / \sum_{i=15}^{64}(MEN_i + WOM_i) \text{ base year})\right]}$$

The value -.50 for a_{1182} is roughly equal to Leff's estimate, and is used in the base run. Values of zero and -1.0 are also used in other runs.

If an "additional" child's parents choose to spend money on educating him rather than in investing that sum in their farm or shop, the choice will show up as a decrease in national saving. The same is true in the government sector; a shift from investment in infra-structure or industry into schooling will show up as a decrease in monetized saving, because most public educational expenses are salaries on current account. Therefore, the adjustment of the savings rate for the youth-dependency effect allows for the cost of the investment in human capital in outfitting additional children for the labor force. This implicitly assumes that average new entrants to the labor force have the same skills as average old entrants, which seems <u>not</u> to be true. But this is beyond the scope of this simulation.

A device to combine the agricultural and industrial sectors is necessary to complete the supply side and constitute an aggregate production function.* This is done here by fixing the relative sizes of the outputs of the two sectors in any given period as a function of the per-consumer-equivalent income (Y/C) in the previous period.** That is, at a lagged Y/C of \$75, total output is set at 35% industrial output and 65% agricultural output. At a Y/C of \$1,000, output is set at 90% industrial output and 10% agricultural output.

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* Theoretically it is conceivable to develop this model with the three mutually-competing outputs of agriculture, industry, and leisure. But this would present great problems both in making it intuitionally satisfactory and in developing calculational methods.

**

$$C_t = \text{consumer equivalents} = .11\ (MEN_1 + WOM_1) + .14 \left[\sum_{1}^{4} MEN + \sum_{1}^{4} WOM\right] + .39 \left[\sum_{5}^{14} MEN + \sum_{5}^{14} WOM\right] + .90 \left[\sum_{15}^{24} MEN + \sum_{15}^{24} WOM\right] + 1.0 \left[\sum_{15}^{99} MEN + \sum_{15}^{99} WOM\right].$$

This calculation of consumer equivalents is based on the weights of Kleiman (1967) and others for the amount of consumption of people of various ages in LDC's. The appropriate weights change in the course of economic development. But the lack of such an adjustment here is not likely to make a major difference in the simulation.

These divisions roughly correspond to the facts for LDC's and MDC's in the world today, and reflect observed income elasticities for the two types of goods. Between these two points the interpolation is linear:

$$\frac{Q_{G,t}}{Q_{F,t}+Q_{G,t}} = .35 + \left[\frac{\left(\frac{Y_{t-1}}{C_{t-1}}\right) - \$75}{\$1000 - 75}\right](.90 - .35). \qquad (9)$$

This function does more than allow for the Engel-effect difference in proportions of agricultural and industrial consumption at different levels of development, however. It also allows for the effect of different dependency ratios on output, as follows: an additional baby born in a given family does not immediately alter total output, but it does immediately lower the income per-consumer-equivalent, hence immediately producing an increase in the proportion of total output that is agricultural.

The accounting identity for the aggregate production function:

$$Y_t = Q_{F,t} + Q_{G,t} = A_{F,t}\, K^{\alpha}_{F,t}\, M^{\beta}_{F,t}\, J_{F,t} + A_{G,t}\, K^{\gamma}_{F,t}\, M^{\varepsilon}_{F,t}\, J_{F,t}. \qquad (10)$$

Given that for any amount of Y_t the amounts of $Q_{F,t}$ and $Q_{G,t}$ are fixed, there is a single-valued amount of Y_t that will be produced for any given input of labor hours, M. (All the other terms in the production functions are predetermined.) Hence the community (in the model) can choose without further complication between just the two goods, leisure and output.

The demand side is a set of tastes for various mixes of leisure and output, i.e., a set of indifference curves. The indifference curves are constructed for a "representative" worker, for intuitional purposes, and

are then summed over the number of workers.

no¶ Each indifference curve is logarithmic to reflect the almost-universal observation in psychology that proportional differences are felt to be equal-size differences.

no¶ This functional form also is commonly assumed by economists (on the basis of intuition and casual empiricism) in discussions of the marginal utility of money, taxes, and so on. Sensitivity experiments have <u>not</u> been done with other functional forms of the indifference curves, but such experiments are no easy matter computationally.

Each indifference curve in Figure 1 at a given time t is equivalent to a straight line drawn on a semilogarithmic graph. The horizontal axis measures work effort from 0% to 100% of possible yearly man hours * (actually 0 to 1.0 for the variable Z). Each indifference curve D_k is formed as follows:

$$D_{k,t} = \text{ORIGIN}_t + b_{k,t} \text{ (antilog } Z_t), \qquad (11)$$

where b_k is the slope that characterizes any one indifference curve within the set of indifference curves at time t. The origin of the indifference function is at a point on the horizontal axis equal to $-.5Z$ in the base run, and at other values in other runs. Only values $0 < Z < 1.0$ are allowed, to reflect the fact that no one can work less than zero hours or more than his maximum. The height of ORIGIN depends upon (a) dependency as measured by the ratio of consumer equivalents to workers; the larger the number of dependents, the more the worker "needs" goods, and the more work he will

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* For data on the variation in hours worked per week in industry in countries with different income levels, see Denison (1967), Kreps (1967), Moore (1971), and Winston (1966). Evidence that consumption aspirations affect work effort is shown in Taiwan by D. Freedman (1972). The higher the aspiration index - a composite of the respondent's plans and desires fo the purchase of consumer durables - the more likely the wives (of wage-and-salary workers) are to be employed. The proportion ranges from 25% to 33% over the aspiration index. Taiwanese families with "modern" consumption patterns are also likely to save more (D. Freedman, 1970).

trade for output, <u>ceteris paribus</u>; (b) the aspirations function RELASP, which rises less than proportionally with real income, in accordance with such studies as Fuchs and Landsberger (197[illegible]) and Centers and Cantril (19 6); (c) the "standard of living (STD_t)"; the basis for the standard of living is actual income, but the standard of living is assumed to change less rapidly than actual income.

$$ORIGIN_t = \left(RELASP_t\right)\left(STD_t\right)\left(\frac{C_t}{L_t}\right). \tag{12}$$

The elements in equation (12) are as follows:

$$STD_t = \frac{Y_{t-1}}{C_{t-1}} \text{ subject to} \tag{13}$$

$$(1-a_{1193})STD_{t-1} \leq STD_t \leq (1+a_{1193})STD_{t-1}.$$

The constraint on equation (13) ensures that the standard of living does not rise or fall at a precipitous rate; its movement is less volatile than that of real income. This reflects the behavior of the consumption function over business cycles, changing less rapidly than income. The constraint parameter a_{1193} is .015 in the base run.

Figure 1

The RELASP aspirations function varies inversely with income, linearly over the range of income \$75 to \$1,000.

$$RELASP_t = a_{141} - a_{142}\left(\frac{\frac{Y_{t-1}}{C_{t-1}} - \$75}{\$925}\right) \tag{14}$$

a_{141} is .4 and a_{142} is .2 in the base run.

$$L_t = \text{labor force} = \sum_{g=15}^{64} MEN_g + .5 \sum_{g=15}^{64} WOM_g. \tag{15}$$

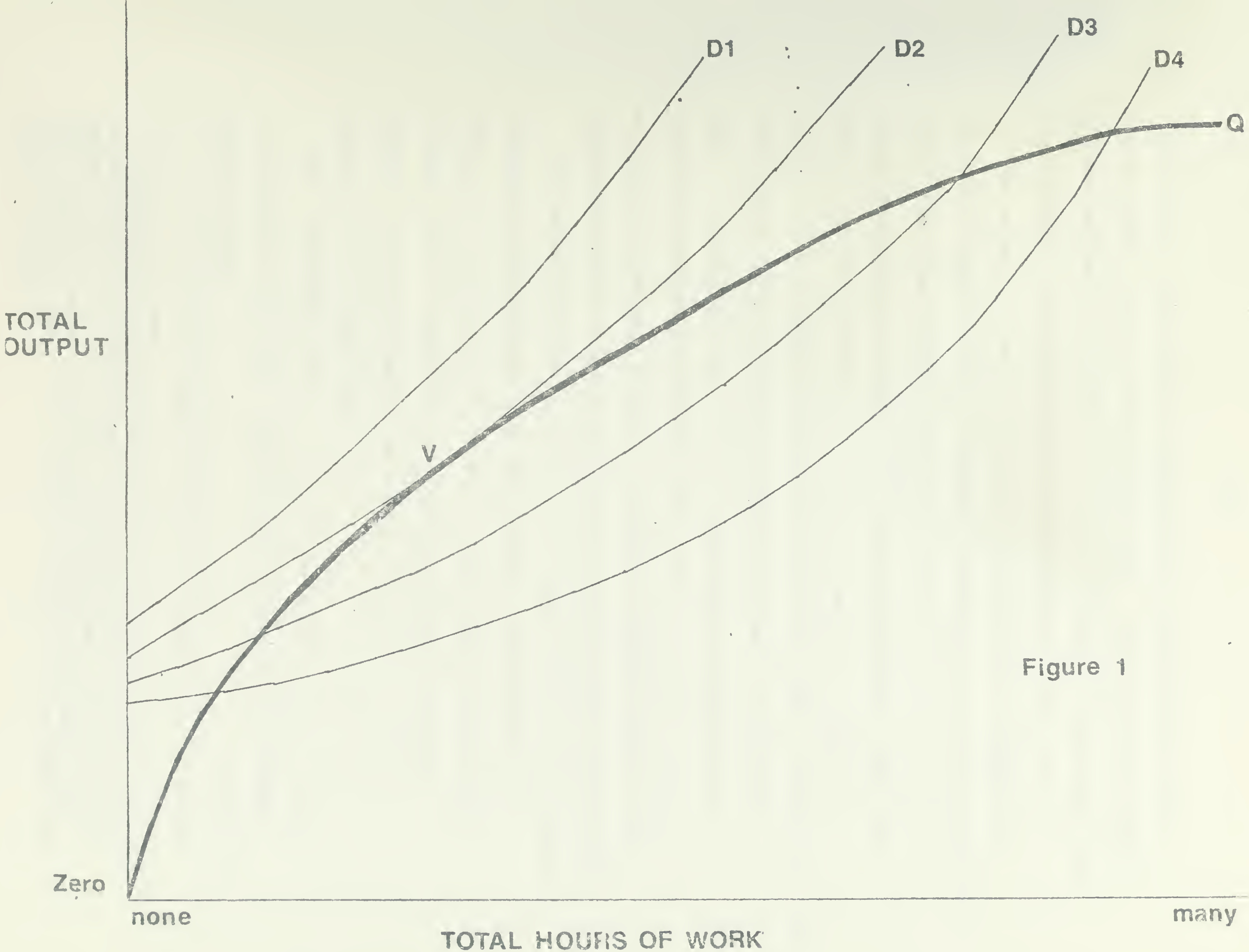

Figure 1

The labor force counts each man aged 15-64 as a male-equivalent worker, and each woman as half a male equivalent worker. (This assumes she spends at least half her time working in the home, work which is outside the scope of our model.) The consumer-equivalent function was defined earlier.

The system is solved by finding the value of Z which corresponds to the point of tangency of (a) the aggregate production function (equation (10)), and (b) the highest among the indifference curves (equation (11)), that touches the production function (see Figure 1). This solution simultaneously fixes the amount of output and the total labor input in man-hours. Formally $L_t D_{K,t} = Y_t$ at the point of solution, or structurally, $\log \frac{Y}{L} = \log D + b_Z$. (16)

All the other elements in the production function and the indifference curves are predetermined by the prior year's values, and hence are constants in the numberical solution. The solution is actually obtained by an iterative convergence program. The values so obtained check well with analytic solutions obtained for the special cases where they could be found.

The numbers of persons of various ages eligible for work in any year are functions of births and deaths in earlier years. The death rate is a function of the prior period's income.* For each cohort in each period, the death rate is a logarithmic interpolation between the mortality schedules for India and Sweden, setting $75 and $1,000 per capita as the endpoints of the interpolation.

The fertility functions - in the form of fertility ratios - are the control variable in the model. Three functions depend upon per-consumer-equivalent income. The function called "Fast falling response to income" (or "Fast fall", for short),

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* Krishnamurty (1966) estimated that for India over the period 1922-1960, the elasticity of the death rate per 1000 population was about -2 with respect to real per capita income, allowing for trend. The elasticities would surely be greater at the lower ages, weaker at the higher ages. (The elasticities surely would be weaker at ranges of income higher than India's, of course.)

declines with an elasticity of 1.0 as income rises. The function called "slow fall" declines with an elasticity of .5,

no ¶ "Up then fast fall" has fertility rise with income at first, and then fertility falls with an elasticity of 1.0 also. The effects of these functions can be gauged best by the number of consumer equivalents in various years as seen in Table 1. But the population size varies from run to run because fertility and mortality are functions of income, and income is a different function of fertility in runs with different economic parameters.

There is also a fertility structure with 1,000 births each year, the starting point of the system (called "Thousand births"). And there is a structure with a constant ratio of births to women aged 15-44 roughly equivalent to a crude birth rate of about 32, called "Constant high." The structure "Constant very high" has a birth/woman ratio equivalent to a CBR of 42. And in some runs there are structures with CBR's of 25 ("Constant moderate") and 37.

THE FINDINGS

1. Using those parameters that seem most descriptive of LDC's today, the very-high birth-rate structures and the very-low birth-rate structures both result in lower long-run per-worker outputs (hereafter referred to as "economic performance") than do birth-rate structures in between. It will surprise no one in this decade that very high birth rates are not best. But the outcome that very substantial birth-rate structures produce higher incomes in the long run than do low birth rates runs very much

against the conventional wisdom. The same result appears with quite different levels of the various parameters.

More specifically, columns 4-6 i Table 1 show the per-worker output in various years for the six experimental birth-rate structures described earlier, and whose population sizes in various years in consumer equivalents are shown in columns 1-3 of Table 1 (or row 1 of Table 2). This data is plotted in Figures 2a [and 2b. In the earliest years the very-low-fertility populations have slightly better economic performance. But as time goes on, the very-low-fertility and very-high-fertility populations fall well behind the moderate-fertility population. Much the same result appears in runs with a wide variety of parameters subject to the discussion to follow.

Table 1 and Table 2

The difference between these results and those obtained by Coale and Hoover (and the more recent work in that tradition such as that by Tempo) is due to the inclusion in this model of several factors omitted from the Coale-Hoover model: a) the capacity of people to vary their work input in response to their varying income aspirations and family-size needs; b) an economies-of-scale social-capital factor; c) an industrial investment function (and an industrial technology function) responsive to differences in demand (output), and d) an agricultural savings function responsive to the agricultural capital/output ratio. These factors together, at apparently-reasonable parameter settings, are enough to offset the capital-dilution diminishing returns effect as well as the effect of dependency on saving found in the Coale-Hoover and Tempo models.

The model surely contains some specifications and parameter estimates that are overly-favorable to population growth. But there are also specification and parameter estimates that are overly-favorable to slow or no population growth. Examples of the latter are: (1) Low depreciation (and the accompanying investment function) turns out to be favorable to relatively low population growth. And the industrial-depreciation parameters used are almost surely too low, which therefore makes the conclusions drawn from the simulation even stronger, a fortiori. (2) Making allowance for the effect of the rise in skills over time of the new labor-force entrants would tend to work against the negative dependency burden and be favorable to population growth, but this effect is not included in the model.

Table 1

Results of Base Run

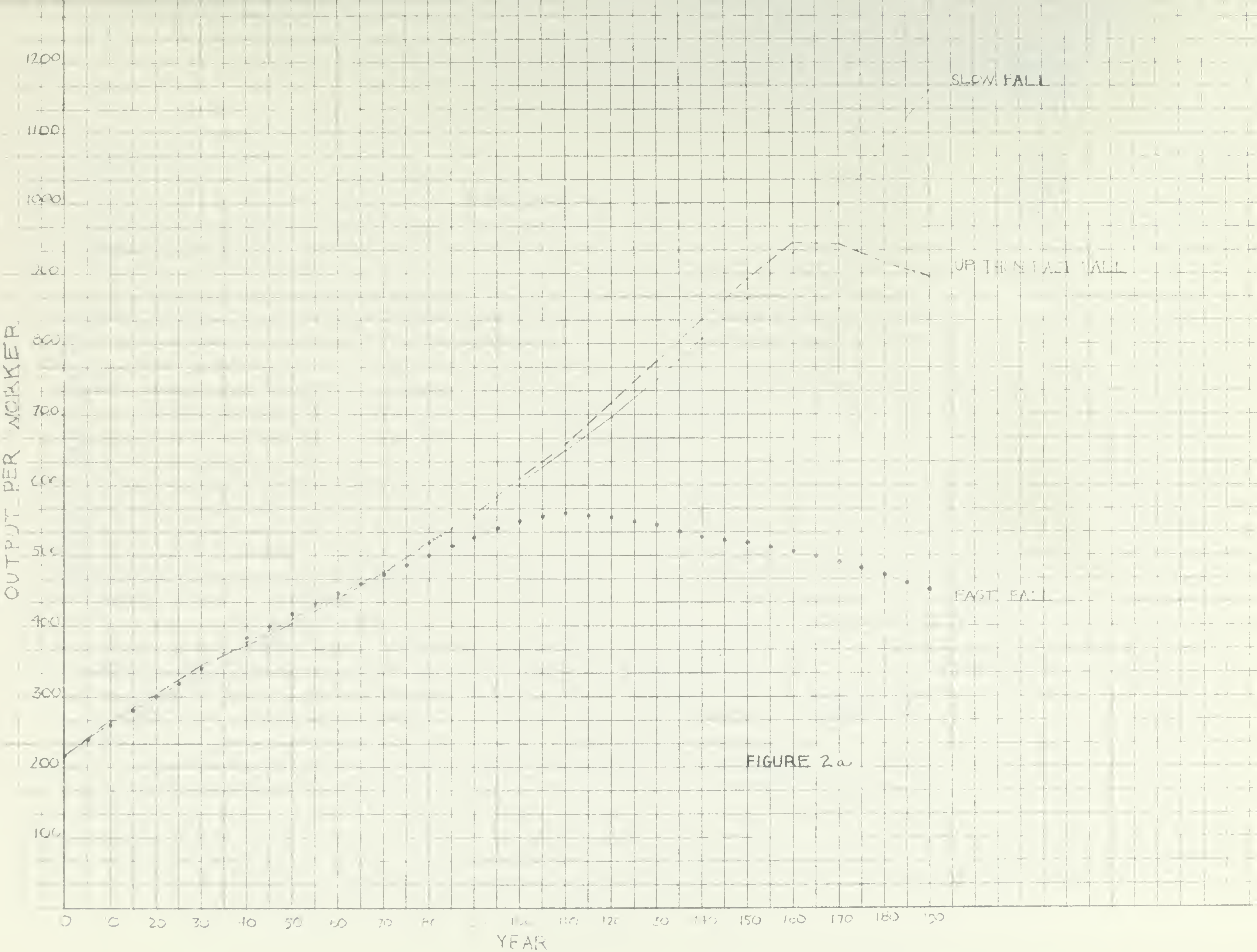
(For a summary of the paran ters, see Table 2, Row 1)

	Consumer Equivalents (C) In tens of thousands of consumer equivalents			Output per Worker $(\frac{Y}{L})$ In Constant Dollars			Index of Labor Utilized in (Z)		
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year	60	120	180	60	120	180	60	120	180
Fast falling fertility response to income	36	34	28	443	552	472	.54	.53	.60
Rise and fast fall	53	105	104	438	715	915	.54	.46	.43
Slow falling response	46	78	111	442	696	1076	.54	.46	.37
Thousand births	39	45	48	446	641	949	.54	.47	.40
Constant moderate 25 ratio	41	73	152	438	680	1058	.54	.46	.37
Constant high 32 ratio	57	158	512	438	692	1025	.53	.47	.40
Constant 37 ratio	73	283	1242	432	666	926	.54	.49	.44
Constant very high 42 ratio	93	477	2723	423	622	812	.55	.52	.48

N.B. $C_{t=0} = 24{,}605$

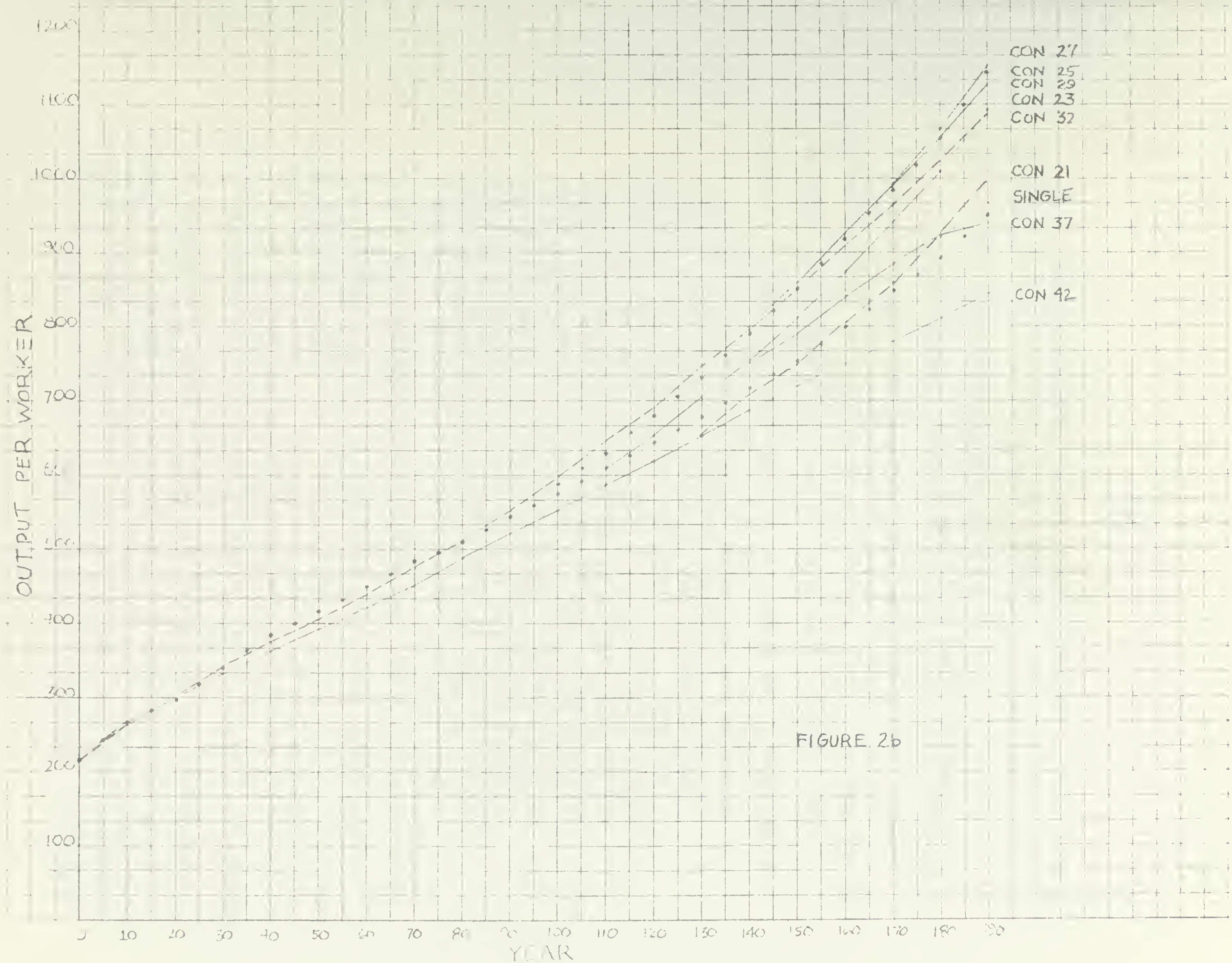
$\frac{Y_{t=0}}{L_{t=0}} = 217$

$Z_{t=0} = .530$



SLOW FALL
UP THEN FAST FALL
FAST FALL
OUTPUT PER WORKER
1200
1100
1000
900
800
700
600
500
400
300
200
100
YEAR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190

FIGURE 2a



OUTPUT PER WORKER
1200
1100
1000
900
800
700
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
YEAR
CON 27
CON 25
CON 29
CON 23
CON 32
CON 21
SINGLE
CON 37
CON 42

FIGURE 2b

2. In the base-parameter run the moderate-fertility populations enjoy more leisure in the long run than do the low-fertility and high-fertility populations. This may be seen in columns 7-9 of Table 1.

3. In many runs with a variety of parameters (columns 19, 21 and 23 in Table 2), over quite a wide range of moderate-to-high birth rates, the effect of fertility upon income is not spectacularly large--seldom as much as 25% even after 180 years (though the difference between low and moderate birth rates is great). This is extremely surprising at first thought. But this is what Kuznets expects:

> ...given the political and social context, it does not follow that the high birth rates in the underdeveloped countries, per se, are a major cause of the low per capita income; nor does it follow that a reduction of these birth rates, without a change in the political and social context (if this is possible), will raise per capita product or accelerate its rate of growth. We stress the point that the source of the association between demographic patterns and per capita product is a common set of political and social institutions and other factors behind both to indicate that any direct causal relations between the demographic movements and economic growth may be quite limited; and that we cannot easily interpret the association for policy purposes as assurance that a modification of one of the variables would necessarily change the other and in the directions indicated by the association. (Kuznets, 1965, p. 29)

Still, this phenomenon demands explanation. And an explanation seems to be forthcoming within this system, as will be seen in the results to be described presently.

4. One important element offsetting the capital-dilution effect is the difference in work done per year under the different birth-rate structures, as may be seen in columns 7-9 of Table 1. In year 120, the average worker works at 52% of capacity in the highest birth-rate variation, and at 47% in the next-highest birth variant. This difference of 5/47 or 10% goes a long way to make up for lesser capital per worker in the higher fertility

variants. In the industrial sector this also makes possible an important effect on investment. (In the agricultural sector, population growth and output increase immediately cause a parallel increase in agricultural investment.) Other factors that help account for the lack of difference in economic performance among the moderate-to-high birth rates will be discussed below.

The effect of the variations in work supplied in response to aspirations and perceived need in the base run may be seen with the aid of a run where the work supplied per worker is held constant in all the birth-rate variations, other parameters being the same as in the base run. The results shown in row 2 of Table 2

Table 2

5. It is of fundamental interest that economic performance does not come out to be a monotonic (inverse) function of fertility. An important element in this finding is the economies-of-scale variable J. Its importance is shown by the fact that when the parameter is set so that there is no increase in social capital as a function of labor-force size rather than the Chenery estimate used in the base run, there is almost (but not quite) a monotonic (inverse) relationship between birth rate and economic performance, as seen in row 3 of Table 2. But the economies-of-scale social-capital factor is not the sole factor, or even the dominant factor, in the inferior performance of the low-fertility structures relative to the moderate-fertility structures. This may be seen in the inferior performance of the lowest endogenous birth-rate structure even with no economies of scale ("Fast falling" in column 12 in row 3 in Table 2). And in various other runs with zero economies of scale,

the relationship is also not monotonic. When depreciation is made higher than usual, for example, the low constant-fertility-ratio population does much better in the first 60 years than does the moderately-high constant-fertility-ratio population, but in the long run higher fertility does much better (row 4 in Table 2). The same is true when investment is made more responsive than usual to output; the low constant-fertility-ratio has eventually declining economic performance, though higher fertility-ratio variations do not (row 5 in Table 2).

When the economies-of-scale effect is twice as great as in the base run, the highest fertility structures have better economic performance than any of the populations with lower birth rates (row 6 in Table 2).

6. The determinants of physical investment are crucial in this model as in all other economic models.* It is a fundamental difference between this and Coale-Hoover-type models that gross industrial investment depends here upon demand, as measured by the change in last year's industrial output less the prior year's output, rather than being a proportional function of absolute output. This reflects the universal fact that investment is responsive to business prospects. It also reflects the historians' recent consensus that demand was a key factor in England's economic development. And the empirical literature on investment in more-developed countries emphasizes the influence of changes in output on investment. And the

* This would be somewhat less true if the effectiveness of labor were made a function of past income, to represent changes in the quantity of education and in its technological level. But educational investment would be very positively correlated with physical investment, despite its less cumulative nature. Therefore, the latter alone may be thought of as a not-too-bad proxy for both physical and educational investment.

concept of the accelerator provides theoretical foundation for this function. Hence it seems that there is every good reason to make the investment function in this model a function of changes in output.

Though the result may seem surprising at first, it is reasonable that a relatively small difference in industrial output should have a large effect on industrial investment. Investors are likely to project a present-period decline (or increase) in output into a future trend. And investment is undertaken with an eye to several periods in the future rather than just one period. Hence the expected trend has a cumulative effect far beyond the output results of a single year.

Inclusion of depreciation explicitly--rather than working with a net investment function--has an important enriching effect upon the model which allows interesting and realistic results to emerge. It is depreciation that brings about a decline in incomes when economic stagnation sets in; without allowance for depreciation, income would remain much the same in such stationary conditions. Such declines in economies are observed both secularly and cyclically, and it is a benefit that the model shows them. Long-run secular declines are mostly found among the lowest-birth-rate trials, and the cause is the failure of output to rise very much. An example of such a decline is seen in the performance of the lowest income-responsive birth-rate structure (row 7 in Table 2), which describes a run with "lower growth" parameters, all the parameters being set at values that seem more appropriate to an LDC in the 19th or 18th century rather than in the 20th century.

Another example of the importance of the depreciation function is seen in two runs with no economies-of-scale that differ in the parameters of depreciation of farm and industrial capital (rows 3 and 4 in Table 2). Where depreciation is faster, the constant-moderate fertility-ratio structure has better economic performance than the constant low-fertility-ratio structure. Where depreciation is slower, the constant low-fertility structure does better. (The explanation is that a bigger labor force increases output and hence increases investment, which is relatively more important when depreciation is faster.)

These results suggest a population "trap"--though a very different sort of trap than the Malthusian trap elaborated by Nelson (1956) and Leibenstein (1954). The nature of this trap is that if population growth declines too fast as a function of increasing income, total output fails to rise enough to stimulate investment. Depreciation is then greater than investment, and income falls. In the model this results in a return to higher fertility and another cycle, though this may not be plausible historically. If--as is more plausible historically--fertility continues to be low, economic performance would continue to decline toward a low-level plateau.

7. The dependency effect of children upon industrial investment has considerable impact on the results. A base run but without such a dependency effect shows a monotonically positive relationship of fertility to income (row 8 in Table 2), whereas otherwise the relationship is curvilinear as seen in the base run (row 1 in Table 2). Removing the dependency effect has the opposite effect from removing the economies-of-

scale from the base run (row 3 in Table 2). And there is probably much more doubt about the fact and size of the dependence effect than about the economies-of-scale effect. This suggests that models such as Coale-Hoover and Enke et al, that embody a dependence effect but not an economies-of-scale effect are seriously biased against population growth for this reason alone, even if for no other.

Removing both economies-of-scale and the dependence effect is pretty much a trade-off (row 9 versus row 1), though the relative strengths of the dependency and economies-of-scale effects are influenced by the rate of growth produced by the other parameters.

8. The advantage of moderate birth rates over low birth rates generally appears only after quite a while - say 75-100 years. This is another reason why the results found here differ from those of the Coale-Hoover and Tempo models, in which the time horizon is only 25 or 30 years (55 years in the Coale-Hoover minor extension), whereas the time horizon here is 180 years (longer in some cases). This points up the grave danger in using short-horizon models in the study of population, whose effects take a long time to begin and much longer to cumulate.

9. In an attempt to understand the difference in the common judgments about the effect of population growth in 18th century England and 20th century India (and other contemporary LDC's), separate sets of parameters were constituted to picture the two situations. The main differences are in the functions for economies-of-scale, agricultural investment response, industrial investment, industrial technology, the maximum increase in aspirations function from year to year, and the extent of increase in aspirations as a function of income. The more specific description is found in the coefficients in rows 10 and 11 in Table 2. The results indicate that high population growth up to very high fertility is indeed very beneficial for economic performance with the parameters chosen to represent England.
And very slow population growth is slightly (and only slightly) better for India than is moderate growth - and zero growth is worse than both. If these sets of parameters represent 18th century England and 20th century India, the different judgments about the effects of population growth on income in the two situations may be considered reconciled.

Though income per capita and output per worker grow slower with Indian parameters than with 18th century English parameters, the simulated Indian population benefits from a much larger quantity of leisure--due to the lower income aspirations set into the Indian model. A run in which the same aspirations function is given to both country situations markedly reduces the leisure differential. But the output-per-worker differential is reduced much less, though substantially (rows 12 and 13 in Table 2).

The reader may wonder how important the economies-of-scale parameter is in the comparison of 20th century India and 18th century England. The

previously-described sets of parameters were therefore run with the same economies-of-scale parameters as in the base run. The results are shown in rows 14 and 15 in Table 2.

10. Several sensitivity experiments were made with the fundamental economic parameters of the system that have no strong theoretical tie to the effect of fertility. These separate experimental variations in the base run include using, a) Cobb-Douglas exponents of .4 and .6 instead of .5 and .5 in the agricultural production function and, b) capital-output ratios of 4 in both industry and agriculture. The insensitivity of the basic findings to these experiments is encouraging. It increases confidence that the basic model is not flawed in a basic structural fashion. And it also suggests that the factors that we have chosen as population-sensitive are indeed more important in this context than are the other structural factors.

Another source of confidence in the model and its results is the fact that the absolute size of the per-worker results is very different with different sets of parameters, but the relative results are much the same, as seen in the various runs in Table 2.

11. The differences in economic performance in the early years seem small in all runs, much smaller than the sorts of differences in performance one finds in the Coale-Hoover model. One of the larger differences is between \$239 and \$210 in "India" in year 60 for the low constant fertility ratio and the highest constant fertility ratio, and even this difference is large compared to the results of other models. (And by year 180, the low-fertility structure comes to have relatively poor economic performance.)

This model yields no direct answers to policy questions. Any population-policy decision must employ a discount factor commensurate with the effects in various periods of the future. And the range of plausible choices of the discount factor is very wide indeed, ranging from an almost-equal weighting of present and future generations' welfare to discount factors that make quite unimportant everything that will happen more than 15 or 20 years in the future. The results of this long-run model may, however, be relevant to policy discussions which do not heavily discount the future. In any case, the main thrust of the model is analytic rather than policy-making.

Nevertheless,

it is natural to ask about the "optimum" fertility structure. Only a small sub-set of the large number of possible fertility structures have been tried, of course, but they would seem to sample the important possibilities. The generalization may be hazarded that some population growth is beneficial in the long run in all the circumstances we examined. The "best" rate of growth in terms of long-run output per worker (or income per consumer equivalent) is relatively slow growth under some reasonable sets of conditions--a doubling in perhaps 90 years--whereas with some other sets of conditions the doubling time for the best economic performance is considerably shorter. But perhaps it is misleading to even discuss the differences, because the differences in economic performance between the "best" fertility structure and a wide range of other moderate-to-fairly-high rates of growth are relatively small by any measure--most especially by comparison to the difference between the economic performance of positive population growth and negative population growth.

Though within the wide range of moderate-to-fairly-high population growth economic performance does not vary much and the palm sometimes goes to higher and sometimes to lower growth, populations with lower (but not declining) fertility almost always have somewhat more leisure--an important economic property of any system. (Populations with no growth or decline in population size do worse in both respects.)

13. Perhaps the most important result in the simulation experiment is that it shows there are some reasonable sets of conditions under which fairly high fertility shows better economic performance at some points in time than does low fertility, and that there are also other reasonable sets of conditions under which the

opposite is true. There are even sets of conditions well within the bounds of possibility under which extremely high fertility offers the highest income per capita and output per worker in the long run. That is, the results depend upon the choice of parameters within the range that seem quite acceptable. This implies that any analytic model of population which concludes that any one fertility structure is unconditionally better than another must be wrong--because that model's construction is too simple, or for other reasons.

The sole exception to this rule of non-generality is fertility so low as to be below replacement. Such a fertility structure does poorly under every set of conditions simulated here, largely because a reasonable increase in total demand is necessary to produce enough investment to overcome the drag of depreciation.

EVALUATION OF MODEL AND FINDINGS

Though the method used here is computer simulation, this model is of a theoretical nature--just as are analytical models.* Both types of models have in common the problem of evaluation and validation. Best of all would be to fit the theoretical outputs to empirical data of the same nature--in this case, year-to-year movements of an economy of the sort being modeled. Development models such as those of Fei-Ranis (1964), and Kelley et al (1972), have done that. But this is not possible here, just as it is not possible with other population models such as Coale-Hoover. The main reason is that the aim of these models is to compare the results of

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* The advantages and disadvantages of computer-simulated theoretical models versus analytical theoretical models are well-known, and need not be discussed here.

population growth structures that have <u>not</u> existed. In such a situation, one may evaluate the validity of a model on these two criteria taken together: 1) the theoretical and empirical reasonableness of the model's structure; and 2) how well the over-all results fit the range of empirical experience. Let us test the model against these two criteria in that order.

1. First, the model includes all the main accepted elements that are found in other LDC population-growth models--such as diminishing returns, and the effect of dependency. Second, it also includes other elements that are generally agreed to be important in qualitative discussions but that are omitted from previous models: demand and its effect on investment, the shift of labor from agriculture to industry, the leisure-output choice, and the effect of aspirations. Third, the model substitutes an accelerator investment function for the constant-proportion-of-output function found in Coale-Hoover and other work in that tradition; an accelerator function has all the weight of economic theory and empirical findings behind it. Taken together, these three aspects of this model's construction should make it more convincing than previous models--having all their good features and a lot more. The reasonableness of the wide range of parameters must be judged by each reader.

2. The results of this model agree better with the historical and cross-sectional data mentioned in the introduction than do previous models.

On the basis of this combination test, this model and its results should be more acceptable than Coale-Hoover and its descendants. The model does, however, have the damning defect that almost everyone "knows" that its results are wrong. Therefore, it has little chance of being taken seriously and it will not even find its way into print very easily.

IS POPULATION GROWTH REALLY BAD FOR LDC'S IN THE LONG RUN?

A RICHER SIMULATION MODEL*

Julian L. Simon

Summary

This simulation model of the effects of population growth in an LDC economy adds several important elements omitted from previous models: the work-leisure choice and the effect of family size on the amount of work done; agricultural and industrial investment functions responsive to demand; depreciation of capital assets; and an allowance for economies of scale and the creation of social infrastructure. These elements, combined with the elements of the standard model and with all parameters estimated from the best available empirical studies, yield results quite different from Coale-Hoover and similar studies. Within the 25-year horizon used by other models, slow or no population growth produces higher per-worker output than does higher population growth, but only slightly. And in the very long run - a horizon of 60-180 years, which is much beyond the horizon of the comparable models in the literature - moderate population growth produces higher per-worker output than does a stationary population. Declining population growth produces uniformly poor results in the long run.

Notes:

1. See Appendix for definitions of the variables.

2. The demand effects are embodied by way of the standard of living (prior year's income) and the dependency effects (population variables).

3. Population effects are shown in heavy lines.

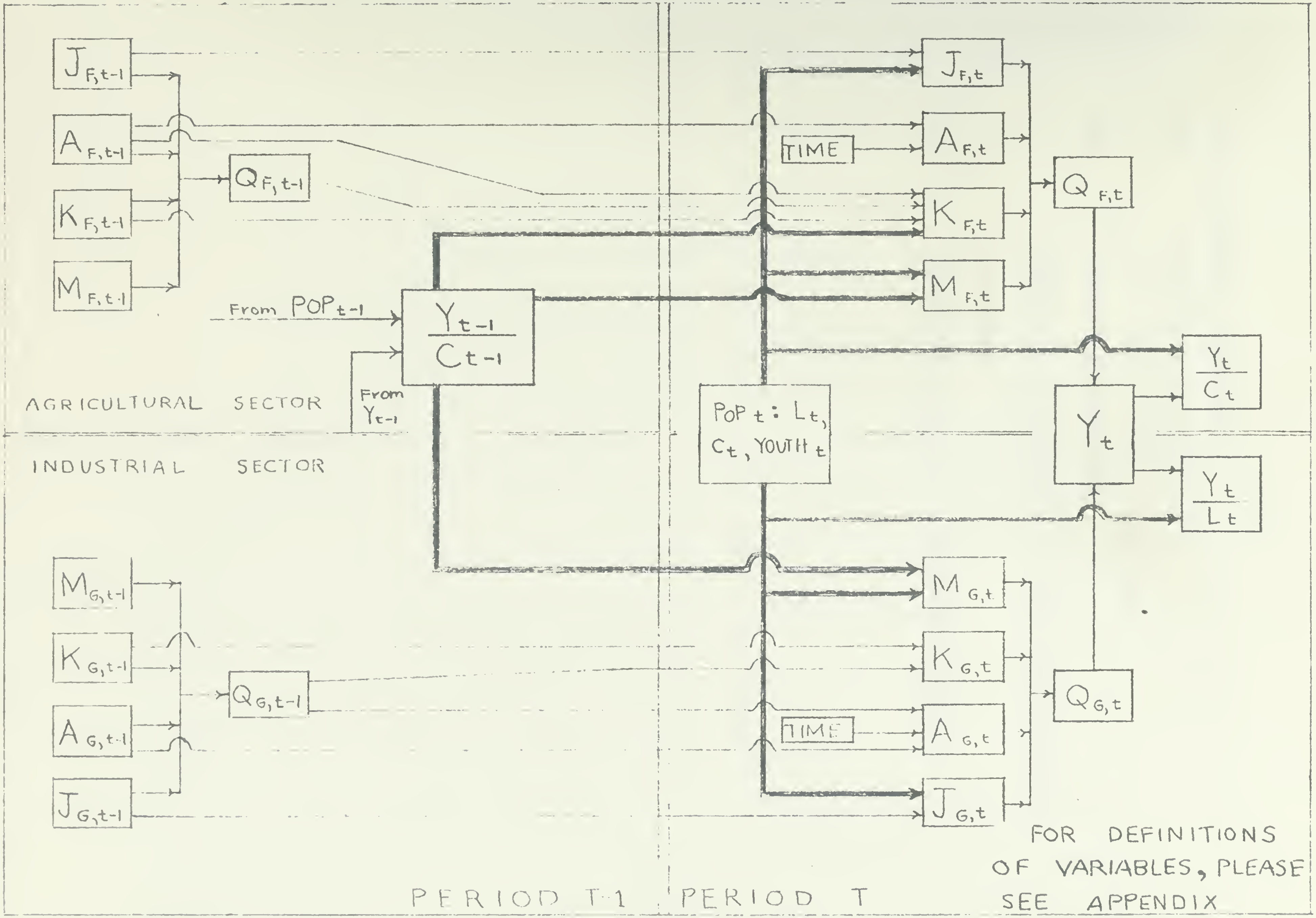
Appendix

List of Variables

(Numbers at end of definition indicate equation in which the variable is defined or specified.)

$A_{F,t}$	= the technological know-how in use in agriculture at time t in in the country being analyzed (equation 5)
$A_{G,t}$	= industrial know-how (equation 7)
C_t	= the number of consumer equivalents
$D_{K,t}$	= the set of indifference curves (equation 11)
F	= designates agricultural farm sector
G	= designates industrial sector
GAP_t	= difference (proportional) between actual and aspired-to agricultural efficiency-capital (equation 4)
J_t	= social overhead capital (infra-structure) such as roads (equation 2)
$K_{F,t}$	= farm capital at time t, most of which is land (equation 3)
$K_{G,t}$	= industrial capital (equation 8)
L_t	= the number of male-equivalent workers available at time t (equation 15)
$M_{F,t}$	= the total number of man-hours worked in agriculture in year t
$M_{G,t}$	= total man-hours worked in industry
MEN_i	= males of age i in year t
$ORIGIN_t$	= origin on vertical axis of indifference curves (equation 12)
$Q_{F,t}$	= agricultural output in year t, not including any saving and investment in agriculture (equation 1)
$Q_{G,t}$	= industrial output, including investment goods (equation 6)
$RELASP_t$	= aspirations level at time t (equation 14)
STD_t	= standard of living at time t (equation 13)

SCHEMATIC OF THE MODEL



FOR DEFINITIONS OF VARIABLES, PLEASE SEE APPENDIX

FIGURE 3

(List of Variables, continued)

$WOM_{i,t}$	= females of age i in year t
Y_t	= total output in year t (equation 10)
$YOUTH_t$	= youth dependency burden
Z_t	= proportion of potential work-hours that are actually worked in a given year t
a_1, a_2...	= parameters
α, β, γ, ε	= exponential parameters in production functions

	(1) ECONOMIES OF SCALE	(2) DEPENDENCY - INDUSTRIA[illegible]	(3) AGRICULTURAL INVESTMENT RESPONSE	(4) AGRICULTURAL DEPRECIATION	(5) INDUSTRIAL INVESTMENT RESPONSE	(6) INDUSTRIAL DEPRECIATION	(7) AGRICULTURAL TECH CHANGE - TIME	(8) INDUSTRIAL TECH CHANGE TIME	(9) INDUSTRIAL TECH. CHANGE RESPONSE	(10) ASPIRATION ORIGIN PROPORTION	(11) CONSTRAINT ON LIVING-STANDARD CHANGE
	a 2	a1182	a1140	a1141	a1181	a1183	a115	a1170	a1171	a141	a143
1 BASE RUN	.10	5	25	.01	.0275	.025	.005	.005	.002	.4	.015
2. FIXED WORK HOURS											
3. NO ECONOMIES OF SCALE	.00	.5	25	.01	.0275	[illegible]	1.005	.005	.002	.4	.015
4 NO ECONOMIES EXTRA DEPRECIATION	.00	5	25	.015	.0275	.037	1.005	.005	.002	.4	.015
5 NO ECONOMIES EXTRA DEPRECIATION EXTRA INVESTMENT	.00	.5	25	.015	.035	.037	1.005	.005	.002	.4	.015
6 DOUBLE ECONOMIES OF SCALE	.40	.5	25	.01	.0275	.025	1.005	.005	.002	.4	1.015
7. LOW GROWTH	.20	5	25	.005	.020	.012	1.0025	.0025	.001	4	.015
8 NO DEPENDENCY	.20	0	.25	.01	.0275	.025	1.005	.005	.002	.4	.015
9. NO ECONOMIES NO DEPENDENCY	.00	0	.25	.01	.0275	.025	1.005	.005	.002	4	.015
10. ENGLAND	.30	5	5	.01	.0275	.025	1.005	.001	.002	5	1.015
11 INDIA	.10	.5	1	.01	.020	.025	1.005	.005	.001	.3	1.0075
12 ENGLAND WITH REGULAR ASPIRATIONS	.30	.5	.5	.01	.0275	.025	1.005	.001	.002	.4	1.015
13. INDIA WITH REGULAR ASPIRATIONS	.20	.5	.5	.01	.0275	.025	1.005	.005	.002	4	1.0075
14 ENGLAND WITH REGULAR ECONOMIES	.20	5	5	.01	.0275	.025	1.005	.001	.002	.5	1.015
15. INDIA WITH REGULAR ECONOMIES	.20	5	1	.01	.020	.025	1.005	.005	.001	.3	1.0075

	ENDOGENOUS FERTILITY STRUCTURES						EXTERNALLY FIXED FERTILITY STRUCTURES									
	(12) FAST FALLING FERTILITY RESPONSE TO INCOME	(13)	(14) RISE AND FAST FALL	(15)	(16) SLOW FALLING RESPONSE	(17)	(18) THOUSAND BIRTHS	(19)	(20) MODERATE CONSTANT CHILD/WOMAN RATIO (25)	(21)	(22) HIGH CONSTANT CHILD/WOMAN RATIO (32)	(23)	(24) CONSTANT 37 RATIO	(25)	(26) VERY HIGH CONSTANT RATIO (42)	(27)
	Y/L	Z	Y/L	Z	Y/L	Z	Y/L	Z	Y/L	Z	Y/L	Z	Y/L	Z	Y/L	Z
1 BASE RUN	472	.60	915	43	1096	37	949	.40	1058	.37	1025	.40			.812	.48
2. FIXED WORK HOURS																
3. NO ECONOMIES OF SCALE	561	.54	623	.47	675	.45	711	.45	669	.45	567	.49			349	.59
4 NO ECONOMIES EXTRA DEPRECIATION	183	85	365	.63	402	.61	163	89	412	.61	357	.64	291	69	232	.73
5 NO ECONOMIES EXTRA DEPRECIATION EXTRA INVESTMENT	332	.70	565	.50	617	.48	415	63	616	.47	524	.51	434	.57	347	62
6 DOUBLE ECONOMIES OF SCALE	451	.63	768	49	1486	.31	1149	.36	1455	.31	1497	.31	1534	.311	1435	.332
7. LOW GROWTH	480	56	742	47	717	.46	579	.49	698	.46	717	.48	407	.51	605	.55
8 NO DEPENDENCY	400	66	824	46	963	.40	741	.46	977	.39	1091	.38	1124	.38	1129	.39
9. NO ECONOMIES NO DEPENDENCY	456	61	617	47	637	.47	610	.50	631	.47	585	.48	541	.50	498	52
10. ENGLAND	287	1.0			851	.62	327	1.0			922	.59			732	.70
11 INDIA	388	.39	364	.39	379	.39	307	.41			358	.39			265	.42
12 ENGLAND WITH REGULAR ASPIRATIONS	286	.75	691	.54	813	47	334	72	829	46	854	47			719	.53
13. INDIA WITH REGULAR ASPIRATIONS	368	.68	466	.59	497	.57	349	.69	502	.56	450	.60			329	69
14 ENGLAND WITH REGULAR ECONOMIES	270	100	641	.85	760	.69	334	1.0	787	66	756	.71	685	.78	604	.89
15. INDIA WITH REGULAR ECONOMIES	432	.39	461	.39	489	.38	347	.41	467	.38	474	39	432	40	384	.42

Output per worker (Y/L) and actual work as a proportion of potential work (Z) in year 180 under various assumed conditions

Summary of Main Structural Equations

$$Q_{F,t} = A_{F,t} K_F^{\alpha} M_F^{\beta} J_t$$

$$\left(\frac{J_{t+1} - J_t}{J_t}\right) = a_{112} \left(\frac{L_t - L_{t-1}}{L_{t-1}}\right)$$

$$\frac{K_{F,t+1} - K_{F,t}}{K_{F,t}} = a_{1140} \; GAP_t - a_{1141}$$

$$GAP_t = \frac{4Q_{F,t} - a_{113} A_{F,t} K_{F,t}}{a_{11e} A_{F,t} K_{F,t}}$$

$$A_{F,t} = a_{115} A_{F,t}$$

$$Q_{G,t} = A_{G,t} K_{G,t}^{\gamma} M_{G,t}^{\varepsilon} J_t$$

$$A_{G,t+1} = A_{G,t} + a_{1170} A_G + a_{1171} \log \left(\frac{Q_{G,t} - Q_{G,t-1}}{Q_{G,t}}\right) A_{G,t}$$

$$K_{G,t+1} = K_{G,t} + A_{1181} \log \left(\frac{Q_{G,t} - Q_{G,t-1}}{Q_{G,t}}\right) (1 - a_{1182} \; YOUTH_t) K_{G,t} - a_{1183} K_G$$

$$\frac{Q_{G,t}}{Q_{G,t} + Q_{F,t}} = .35 + \left(\frac{\$75 - \dfrac{Y_{t-1}}{C_{t-1}}}{\$75 - \$1000}\right)(.90 - .35)$$

$$Y_t = Q_{F,t} + Q_{G,t}$$

$$D_{k,t} = ORIGIN_t + b_{k,t} \; (\text{antilog } Z_t)$$

$$ORIGIN_t = L_t \; (RELASP_t)(STD_t) \left(\frac{C_t}{L_t}\right)$$

$$STD_t = \frac{Y_{t-1}}{C_{t-1}} \text{ subject to}$$

$$(1 - a_{1193}) \; STD_{t-1} \leq STD_t \leq (1 + a_{1193}) \; STD_{t-1}$$

$$RELASP_t = .4 - .2\left(\frac{Y_{t-1}}{C_{t-1}}\right)$$

$$LD_t = Y_t$$

$$Mortality_t = f\left(\log \frac{Y_{t-1}}{C_{t-1}}\right)$$

$L_t = MEN_t + WOM_t$ aged 15-64

Fertility = various endogenous and exogenous functions.

REFERENCES

Ester Boserup, The Conditions of Agricultural Growth (London: George Allen and Unwin, 1965).

John Lossing Buck, Chinese Farm Economy (Chicago: University of Chicago Press, 1930.

Richard Centers and Hadley Cantril, "Income Satisfaction and Income Aspirations," Journal of Abnormal and Social Psychology, 41, January 1936, 64-69.

Hollis B. Chenery, "Patterns of Industrial Growth," American Economic Review, 50, September, 1960, 624-654.

Jean-Claude Chesnais and Alfred Sauvy, "Progrès économique et accroisement de la population, une expérience commentée," Population, 28, Juillet/Octobre 1973, 843-57.

Colin Clark, Conditions of Economic Progress (New York: Macmillan, 1957, 3rd Edition.)

Colin Clark, Population Growth and Land Use (New York: St. Martins, 1967).

Ansley J. Coale and Edgar M. Hoover, Population Growth and Economic Development in Low-Income Countries (Princeton: Princeton University Press, 1958).

J. Conlisk and D. Huddle, "Allocating Foreign Aid: An Appraisal of a Self-Help Model," Journal of Development Studies, July, 1969.

Phyllis Deane and W. A. Cole, British Economic Growth, 1688-1959 (Cambridge: Cambridge University Press, 1964).

Edward F. Denison, Why Growth Rates Differ (Washington: Brookings 1967).

Richard Easterlin, "Effects of Population Growth in the Economic Development of Developing Countries," The Annals of the American Academy of Political and Social Science, 369, January, 1967.

Stephen Enke, et al, Economic Benefits of Slowing Population Growth (Santa Barbara: Tempo, 1970).

Stephen Enke, Economics for Development (New York: Prentice-Hall, 1963).

D. E. C. Eversley, "Population, Economy, and Society," in D. Glass and Eversley, Population in History (London: 1965).

D. E. C. Eversley, "The Home Market and Economic Growth in England, 1750-1780," in E. L. Jones and G. E. Mingay (eds.), Labour and Population (London: Arnold, 1967).

John C. H. Fei and Gustav Ranis, Development of the Labor Surplus Economy (Homewood: Irwin, 1964).

Deborah S. Freedman, "Consumption Aspirations as Economic Incentive in a Developing Economy - Taiwan," mimeo 1972.

Claudio J. Fuchs and Henry A. Landsberger "'Revolution of Rising Expectations' or 'Traditional Life Ways'? A Study of Income Aspirations in a Developing Country," Economic Development and Cultural Change, 21, January, 1973, 212-226.

Donald Glover and Julian L. Simon, "The Effects of Population Growth upon Intra-Structure: The Case of Road Building", University of Illinois Mimeo, 1973.

John Habakkuk, "Population Problems and European Economic Development in the Late Eighteenth and Nineteenth Centuries", American Economic Review, LIII, May 1963, 607-618.

Government of India, Studies in Farm Management, various years.

Allen C. Kelley and Jeffrey G. Williamson, "Writing History Backwards: Meiji Japan Revisited", The Journal of Economic History, XXXI, December 1971, 729-776.

Allen C. Kelley, Jeffrey G. Williamson, and Russell J. Cheatham, Economic Dualism in Theory and History (Chicago: University of Chicago Press, 1972.

Allen C. Kelley, "Demand Patterns, Demographic Change and Economic Growth", Quarterly Journal of Economics, LXXXIII, February, 1969, 110-126.

E. Kleiman, "A Standardized Dependency Ratio", Demography, 4, No. 2, 1967, 876-893.

Juanita M. Kreps, Lifetime Allocation of Work and Leisure, Research Report No. 22, U.S. HEW, Social Security Administration, 1967.

K. Krishnamurty, "Economic Development and Population Growth in Low Income Countries: An Empirical Study in India," Economic Development and Cultural Change, 15, October 1966, 70-95.

Simon Kuznets, "Demographic Aspects of Modern Economic Growth", paper at World Population Conference, Belgrade, September, 1965.

____________, "Population and Economic Growth", American Philosophical Society Proceedings, III, June 1967, 170-193.

____________, Modern Economic Growth (New Haven: Yale, 1966).

Nathaniel H. Leff, "Dependency Rates and Saving Rates", American Economic Review, LIX, December 1969, 886-896.

Harvey Leibenstein, A Theory of Economic Demographic Development (Princeton: Princeton University Press, 1954).

William Arthur Lewis, The Theory of Economic Growth (London: George Allen and Unwin, 1955).

Peter Mathias, The First Industrial Nation (London: Methuen, 1969).

Franklin Mendels, "Industry and Marriages in Flanders Before the Industrial Revolution", in Paul Deprez (ed.) Population and Economics (Winnipeg: University of Manitoba Press, 1970).

Geoffrey H. Moore and Janice Neipert Hedges, "Trends in Labor and Leisure," Monthly Labor Review, 94, February 1971, 3-11.

Gunnar Myrdal, Asian Drama, (New York: Random House, 1968).

Richard R. Nelson, "A Theory of the Low-Level Equilibrium Trap in Underdeveloped Economies", American Economic Review, 46, December 1956, 894-908.

A. Sen, "Peasants and Dualism With or Without Surplus Labor," Journal of Political Economy, 74, October 1966, 425-50.

B.H. Slicher von Bath, The Agrarian History of Western Europe, A.D. 500-1850 (London: Arnold, 1963).

M. Stockwell, "Some Observations on the Relationship between Population Growth and Economic Development During the 1960's," Rural Sociology, 37, December 1972.

Anthony P. Thirlwall, "A Cross Section Study of Population Growth and Per Capita Income in a Production Function Framework", mimeo, 1971.

A.R. Tussing, "The Labor Force in Meiji Economic Growth: A Quantitative Study of Yamanishi Prefecture", in K. Ohkawa, B.F. Johnston, and H. Kaneda (eds.) Agriculture and Economic Growth: Japan's Experience (Tokyo: University of Tokyo Press, 1969), quoted in Kelley and Williamson, 1972.

Jan de Vries, "The Role of the Rural Section in the Development of the Duth Economy: 1500-1700", PhD thesis, Yale, 1969

Gordon C. Winston, "An International Comparison of Income and Hours of Work," Review of Economics and Statistics. XLVIII, February 1966, 28-39.

Pan A. Yotopoulos and Lawrence J. Lau, "On Modeling the Agricultural Sector in Developing Economies: An Integrated Approach of Micro and Macroeconomics," mimeo, June 1973.